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ABSTRACT

The Fissile Material Transparency Technology Demonstration occurred at Los Alamos National Laboratory, August 14–17, 2000. The demonstration showed the determination of six attributes (Pu presence, Pu isotopics, Pu mass, absence of oxide, symmetry, and age) on unclassified plutonium samples and a US nuclear weapons component. The demonstrations showed that a six-attribute measurement system with information barrier could be fabricated and was capable of protecting classified information. In order to measure the six attributes, a high-resolution gamma-ray spectroscopy system and neutron multiplicity system were developed. This talk discusses the neutron multiplicity system, along with data taken on the unclassified samples.

INTRODUCTION

The Fissile Material Transparency Technology (FMTT) Demonstration [1] used a commercially available shipper/receiver counter [2], which measured the neutrons emitted from the given samples. The shipper/receiver counter was used as a neutron multiplicity counter (NMC). The outputs of the neutron measurements were used in determining three attributes: (1) mass, (2) absence of oxide, and (3) symmetry. The neutron detector used an active splitter to provide signals for both the Symmetry Analyzer and the NMC Analyzer. The NMC Analyzer calculated ^{240}Pu-effective mass (m), (α,n)/spontaneous fission ratio (α), and leakage multiplication (M) from the multiplicity distribution.

Any measurement of mass, whether it is an active or passive measurement, requires isotopic data to extract the total plutonium mass. The ^{240}Pu-effective mass was folded with the isotopic ratio from the PU600 Analyzer [1] results to provide the total plutonium mass. The absence of oxide was determined by combining the results from gamma-ray spectroscopy (absence of indicator line via PU900 Analyzer) with α. The eight detector bank outputs were sent to the symmetry analyzer to determine the symmetry of the item being measured.

A neutron multiplicity counting system has three major elements. The first is an efficient detector (typically 40-55%) with a low die-away time and low dead time. In the case of the FMTT demonstration, the counter used had an efficiency of ~12% and was adequate for the proof of principle, but was not optimized for NMC measurements. Second, the signals produced in the detector are then processed by electronics to obtain the multiplicity distribution from the neutron pulse stream. Finally, a mathematical model is used to relate the measured quantities to the processes that produce the neutron pulse stream (the "point model"). This is performed in the NMC Analyzer. Further details of neutron multiplicity counting can be found in Application Guide to Neutron Multiplicity Counting [3].

Neutron Multiplicity Counter (As Built)

The FMTT demonstration used a shipper/receiver counter, shown in Figure 1, which was designed specifically for confirmatory measurements of 30-gallon drums. The system consists of 32 ^{3}He tubes mounted within the four walls of a rectangular polyethylene enclosure. The commercial system had the features of two doors, a drum roller, a drum positioner, and a flattened vertical efficiency response. Eight detector pods performed the neutron detection with four ^{3}He tubes in each pod. The inner cavity and exterior is lined with cadmium.

The neutron detectors and polyethylene of the NMC are located in a solid metal enclosure that provides shielding and physical protection for the detector.

Figure 1: Shipper/Receiver counter used in FMTT demonstration as a NMC. Shown in the picture is the modified 30-gal drum used for the unclassified sources with the removable drawer held by Rick Anderson.

The counter was taken out of ten years of storage and used for the FMTT demonstration. The junction boxes at the top of each pod had their desiccant replaced and were resealed with RTV. When the system was powered up, one of the Amptek pre-amplifiers had failed and was replaced. The Amptek modules are located in a sealed, solid aluminum box to prevent condensation and prevent external sources from producing spurious events in the preamplifiers. The rollers and drum positioner were removed and replaced with the security switches and positioner for the drums being used in the measurements. Active signal splitter and derandomizer circuits were added to the system.

During the testing and integration of the system, an eight-channel active splitter box was installed between the Amptek modules and the 32-channel derandomizer. The signal splitter is required so that the NMC Analyzer and Symmetry Analyzer can adequately share the same signal, while preserving signal integrity. With the signal splitter in place, each analyzer had a separate line driver. The use of a passive splitter (i.e. BNC "T" connector), resulted in signal degradation and reflections. The shift register would analyze these reflected pulses, and at times, produce count rates that were twice what was expected.

One of the limitations of a thermal neutron coincidence counting system is the count rate that the system can handle because of dead time. A derandomizing circuit [4] was used to reduce the overall dead time of the system. The derandomizer circuit separates simultaneous events that occur between pods (Amptek modules) and removes the overlap between output pulses. The derandomizer does not affect the dead time inherent in the tubes or in the individual pods. The signals were transported from the NMC to the shielded enclosure, which contained the signal processing electronics and NMC analyzer.

NMC Signal Processing Electronics and Analyzer

The neutron signals from the NMC were processed by a Portable Shift Register-B (PSR-B [5]). The PSR-B recorded the neutron multiplicity distributions. The PSR-B also provided +5V and High Voltage (HV) to the ^{3}He detector pods. The signals from the NMC were recorded into multiplicity distributions and sent to the NMC Analyzer. The commercial PSR-B did not have an adequate 5-V power supply for providing the required current for the NMC, active splitter, and derandomizer. A commercially available replacement was used. The internal HV power supply was shipped with the incorrect resistance chain, which resulted in long ramp-up and ramp-down times in the HV. This was replaced.

The NMC Analyzer controlled the PSR-B through an RS-232 serial port using a derivative of the INCC software [6]. The analyzer was built on a PC-104 architecture and ran a DOS operating system. The software was stored in ROM, memory that cannot be modified or erased. The analyzer software was written to perform the multiplicity analysis on the data collected by the PSR-B. The system was designed to perform a background collection, measurement control, and attribute verification.

The background measures the neutrons from surrounding materials and cosmic ray interactions. Detectors must be designed to mitigate these effects. The measurement control runs were necessary to check the functioning of the detector and electronics. Typically, this is done by decay correcting the measured doubles rate of a ^{252}Cf source. Because we were not using any clocks in the system, a ratio of the doubles to singles rate was used to determine that the system was functioning properly.

The attribute verification mode utilized the multiplicity analysis. Three fundamental processes contribute to the neutron emission from plutonium samples. The neutrons are produced by spontaneous fission, (α,n) reactions, and induced fission. Neutron coincidence counting (i.e. doubles counting) has been used by the IAEA for many years. Problems arise when one assays materials that differ from the representative samples (i.e. (α,n) rate and Multiplication). Multiplicity counting collects data on three parameters: singles, doubles, and triples. These are then related to the sample mass, multiplication and α through the point model. Multiplicity counting has the benefit of not needing representative standards.

The results of the background, measurement control, or attribute verification run were passed to the computational block. The computational block would combine the information from the NMC, Symmetry, PU600, and PU900 analyzers to determine mass, absence of oxide, and symmetry. All comparisons to threshold are done in the computational block.

The NMC detector, PSR-B and NMC analyzer all operate independently of the configuration of the system. They at no time know whether the system is in “open” or “secure” mode.

Prototype Suggestions

With the ability to look back at the system and determine what would improve the system, the following items are proposed. One of the difficulties with the shipper/receiver counter was its very low efficiency, which led to very long count times. An optimized counter, such as the Large Neutron Multiplicity Counter [7], would improve confidence and reduce the measurement time. An optimized counter would also be more robust and capable of handling a wider range of materials without producing false negatives.

Another tool used to reduce the count time is an upgrade to the PSR-B. The Intelligent Shift Register (ISR) and Advanced Multiplicity Shift Register (AMSR) both use the fast accidentals technique, which can reduce the count time by 40% [8]. The ISR is preferred because of its reduced memory and communication functions.

Further decisions need to be made regarding the software. The software must have a time delay to account for the HV ramp-up. The exact time needed depends on the HV resistance chain. Error conditions and system failures must be fully evaluated and handled by the software. Various uses of the m, α, and M results from multiplicity counting have been discussed. Both α and M may be used to bracket metals vs. oxide. Some changes would be merely cosmetic, such as the output in both Russian and English.

Overall, one major improvement would be the integration of the neutron and gamma-ray detectors. This would improve the resolution of the high purity germanium counters with minor effects on the neutron count rate.

Conclusions

From the FMTT demonstration, we were able to identify not only some of the technical issues, but were also able to deal with some of the implementation and operational issues. We did not, however, address operational issues for continuous use in a facility nor all of the authentication and certification issues for a given regime. Neutron Coincidence/Multiplicity counters are very robust.

For this particular counter, we replaced one Amptek module and desiccant after 10+ years in storage. For this particular application we identified the need for an active splitter and derandomizer for the long cables and multiple analysis systems. An optimized NMC with higher efficiency (~30%), shorter die-away time (~40ms), and use of and Intelligent Shift Register would result in a greatly reduced count time. This would have allowed for additional measurements or testing of the system.

Overall the system performed as expected.

Acknowledgements

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